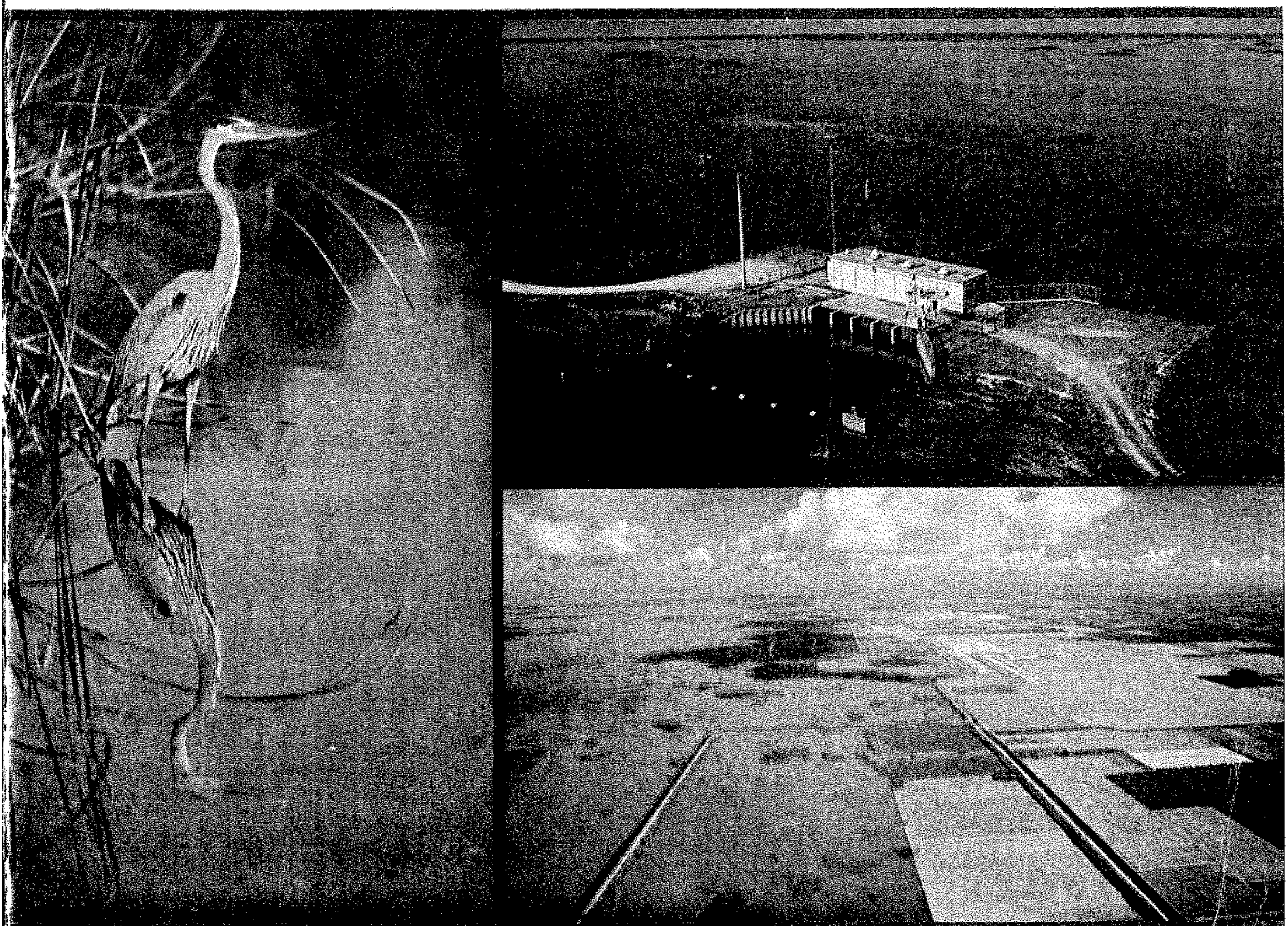
SURFACE WATER IMPROVEMENT AND MANAGEMENT PLAN FOR

THE EVERGLADES



SOUTH FLORIDA WATER MANAGEMENT DISTRICT

APPENDICES - March 13, 1992

EVERGLADES SWIM PLAN

APPENDIX F

Documentation of Models Used to Determine the Size of Stormwater Treatment Areas

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DOCUMENTATION OF MODELS USED TO DETERMINE THE SIZE OF STORMWATER TREATMENT AREAS

A. OVERVIEW

Approximately 553,000 acres of land south of Lake Okeechobee is used for agricultural purposes and is called the Everglades Agricultural Area (EAA) (**Figure 1**). Soils in this area are comprised of rich organic peat and muck and portions of this area have been used for 70 years primarily for production of sugarcane, vegetable, and sod. A canal network operated by the South Florida Water Management District (SFWMD) runs through the EAA. Agriculture draws irrigation water from the canals but also pumps water back into the canals when soils become too wet during local rainfalls. During periods when the soil is exposed to air, oxidation occurs, leading to soil subsidence of approximately 0.025 m/y. The oxidation process leads to the formation of soluble reactive phosphorus that, combined with phosphorus from rainfall and fertilizer, can drain into the SFWMD canals when heavy rainfall necessitates pumping water off the agricultural land.

Phosphorus that is exported via the SFWMD canals from the EAA to the Loxahatchee National Wildlife Refuge (LNWR) and eventually Everglades National Park (ENP) has been identified as a present and potential threat, respectively, to the ecological integrity of these natural areas. Towards decreasing that threat, stormwater treatment areas (STAs) have been proposed that will filter EAA runoff through natural vegetation before it reaches the LNWR, the Water Conservation Areas (WCA), and ultimately the ENP. Described here then, is a modeling approach used to calculate the size of the STAs necessary to filter EAA water to attain acceptable phosphorus levels at the inputs to the LNWR and WCAs. Land for the STAs is to be acquired from the EAA and their general location is indicated in **Figure 1**.

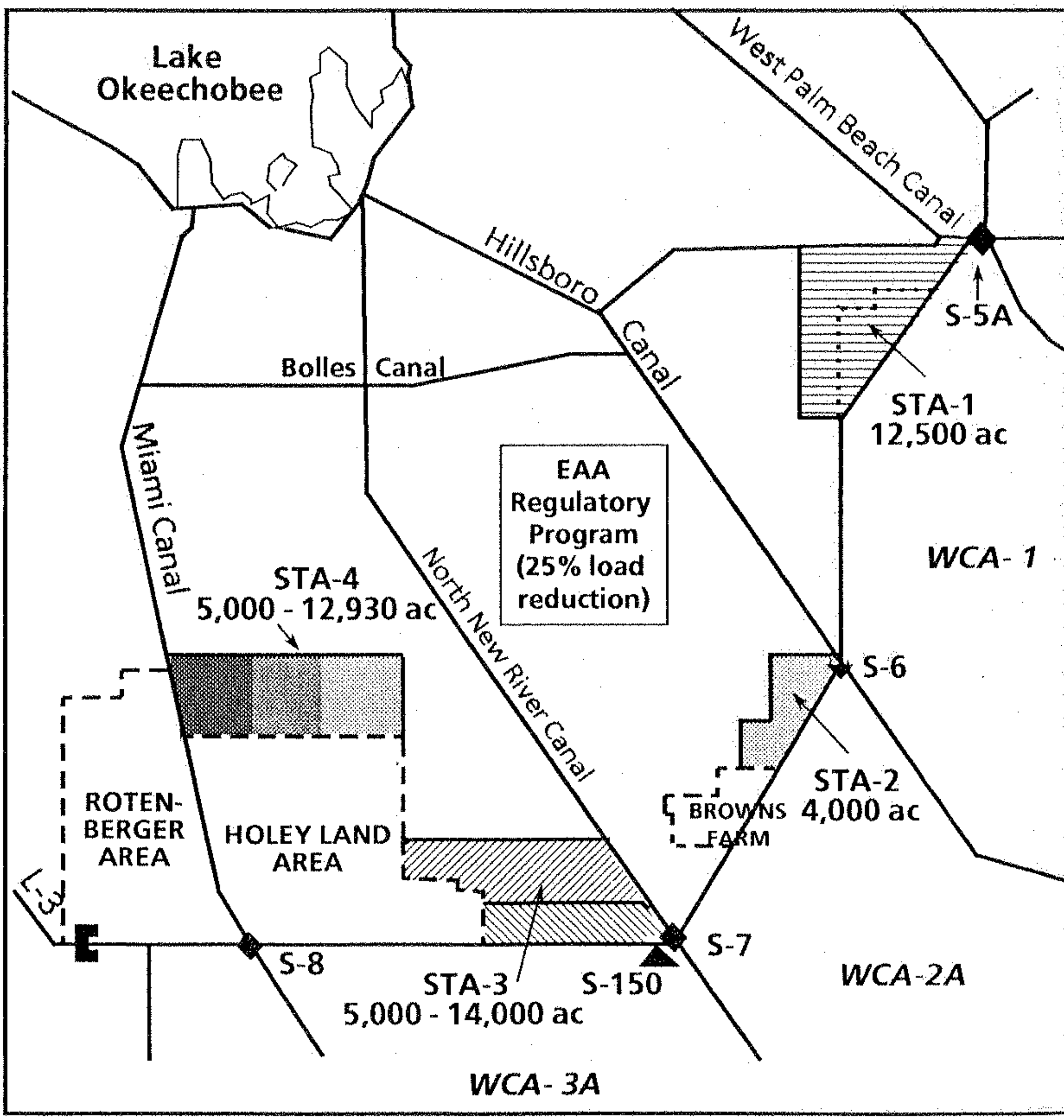
B. MODEL DESCRIPTION

1. Conceptual Basis

The hydrology of the STAs is anticipated to be sheet flow, mimicking characteristics of marshes that existed before establishment of the EAA. Therefore, the model was designed to approximate these hydrologic conditions. In addition, the model was designed with the flexiblity to assess the effects of temporal variability of hydrologic and phosphorus inputs and spatial variability of vegetation type, water retention time, and other factors that could affect filtration efficiency. For the purposes of the management actions required by this study, however, all simulations were run with constant, average water and phosphorus inputs.

The model balances water quantity and phosphorous mass in a series of discrete, linked cells as presented in **Figure 2**. As will be discussed in detail below, this linked cell approach reasonably reproduced the phosphorus filtration characteristics of WCA-2A. This is important because WCA-2A has received EAA phosphorus inputs since about 1960, and has, in essence, functioned as an STA for thirty years. Given adequate information on phosphorus inputs to WCA-2A and its

Figure 1. Generalized Locations and Sizes of Proposed Stormwater Treatment Areas (STAs).*



*Note: map is not drawn to scale.

hydrologic characteristics, a model built to design the STAs should be able to reasonably reproduce measured phosphorus filtration characteristics of WCA-2A.

Hydrologic flows for each model cell include upstream surface water inputs, outputs to downstream cells, precipitation inputs and evapotranspiration. Groundwater interactions are not explicitly addressed. Equations governing the hydrologic mass balance are shown in **Table 1**.

Figure 2. Conceptual diagram of linked-cell model for simulating major hydrologic and phosphorus transport characteristics of STAs.

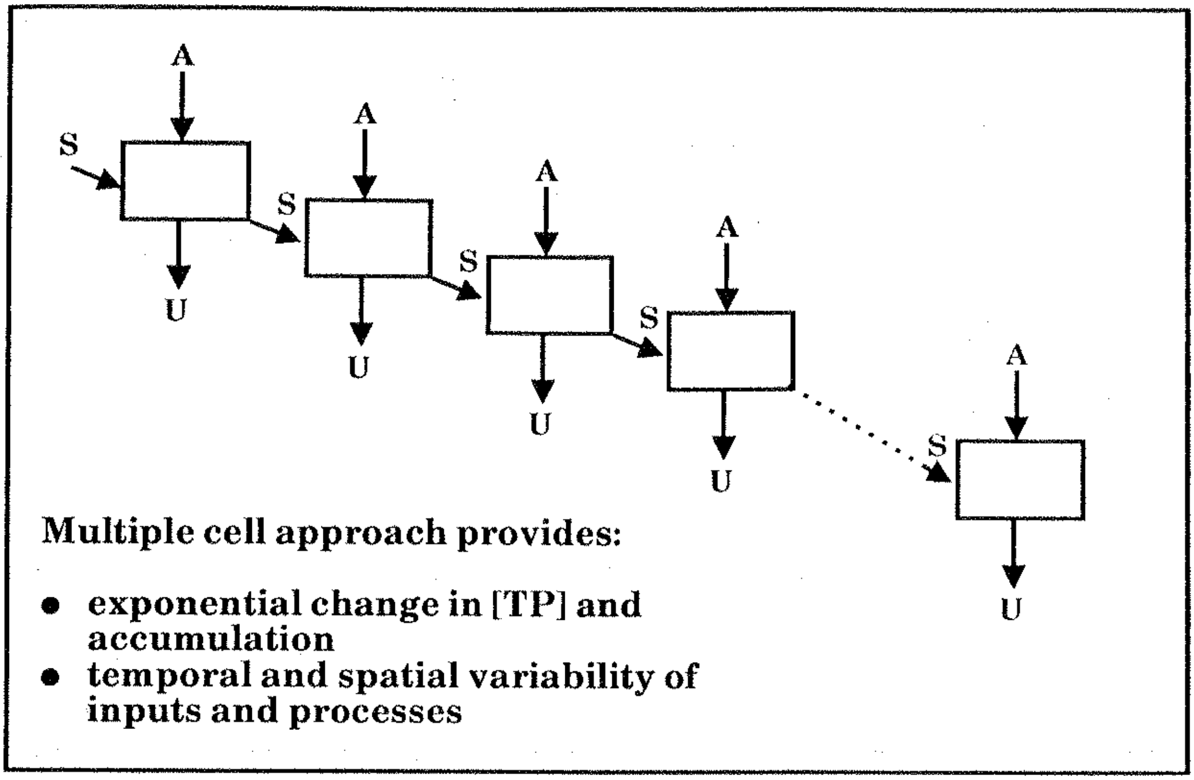


Table 1. Equations governing the hydrologic mass balance of each cell in the STA.

$$
\begin{aligned}
\text{Cell } H_2O\ (km^3)_{t+1} \quad = \quad & \text{Cell } H_2O\ (km^3)_t \\
& + \text{input } (km^3/y) \\
& \qquad [\text{basin or upstream cell output } (km^3/y)] \\
& + \text{precip } (km^3/y) \\
& \qquad [\text{area } (km^2) \times \text{precip } (km/y)] \\
& - \text{ET } (km^3/y) \\
& \qquad [\text{area } (km^2) \times \text{ET } (km/y)] \\
& - \text{output } (km^3/y) \\
& \qquad [\text{area } (km^2) \times \text{ET } (km/y)]
\end{aligned}
$$

The phosphorus mass balance includes surface water inputs and outputs to downstream cells, atmospheric deposition, and net flux of aqueous phosphorus mass to the sediments. Equations governing the phosphorus mass balance are shown in **Table 2**. The net flux term represents the sum of all processes affecting the bi-directional vertical movement of phosphorus between soil and water. Such processes include phosphorus uptake by plants, soil-water phosphorus equilibria, resuspension of phosphorus into the water and settling of phosphorus adsorbed to suspended soil particles. Here, the net flux term is always a loss from the aqueous phosphorus mass to the sediments, that is, the downward flux of phosphorus from water is always greater than return flux from sediments to water. Although the net flux term aggregates many important processes that could be examined individually for their relative importance, this aggregate approach has been applied successfully for management purposes in other systems (Chapra and Sonzogni, 1979; Fontaine and Lesht,1987; Lesht et al, 1991; Mitsch,1991).

Table 2. Equations governing the phosphorus mass balance of each cell in the STA.

$$
\begin{aligned}
\textbf{Cell mass TP (mt)}_{t+1} = \; & \textbf{Cell mass TP (mt)}_t \\
& + \textbf{input mass (mt/y)} \\
& \qquad \textbf{[mt/y]} \\
& + \textbf{precip (mt/y)} \\
& \qquad [\text{mt/km}^3 \times \text{area (km}^2) \times \text{precip (km/y)}] \\
& - \textbf{net settling mass (mt/y)} \\
& \qquad [\text{mt/km}^3 \times \text{area (km}^2) \times \text{km/y}] \\
& - \textbf{output (mt/y)} \\
& \qquad [(\text{mt/km}^3) \times H_2O \text{ outflow (km}^3\text{/y)}]
\end{aligned}
$$

2. Data Inputs and Constraints

Hydrology. Expected annual average surface water inputs to the four STAs were determined using data from the period of record (POR is water years 1978-1989) and adjusting it for water supply bypass, EAA acreage removed from production and used as STAs, and retention of water used by the EAA as part of Best Management Practices (BMPs). The hydrologic adjustments are presented in Table 3. Adjustments correspond to that portion of the average annual surface water input that will not flow through the STAs. Adjustments for water supply bypass were made because it is assumed that they would continue indefinitely. Adjustments were made for EAA acreage that would be transformed into STAs because the water is no longer expected to run off the STA in the manner it did when farmed. It is realistic to assume that BMPs installed in the EAA for the purpose of phosphorus retention should retain no more than 20 percent of the water that would naturally leave the EAA as runoff. Precipitation of 1.14 m/y and evapotranspiration of 1.34 m/y was assumed constant across STAs. A 14 day retention time was enforced, by design, on all STAs.

Table 3. Hydrologic flows (ac-ft) to STAs through SFWMD structures after adjustments.*

STA	A Average Annual POR Flows	B Water Supply Bypass	C Land Converted to STAs	A-(B+C) Adjusted Annual POR Flows	0.8[A-(B+C)] Adjusted for EAA BMPs
1 (S-5A)	312,835	7,864	31,618	274,021	218,893
2 (S-6)	155,657	23,511	4,864	128,093	102,150
3 (S-7+S-150)	275,642	33,239	8,918	233,485	186,464
4 (S-8)	311,314	40,536	26,754	244,025	194,571
TOTALS	1,053,927	105,393	72,964	883,677	702,888

706,942

206,176,7354

* 50 ppb effluent goal
8 m/y apparent settling rate
25% TP retention by BMPs
20% maximum water retention by BMPs
Numbers may not add up exactly due to rounding
Estimates based on refined estimates (@ 9/5/91) of basin sizes.

Phosphorus. STAs were designed to discharge 50 ppb Total Phosphorus (TP) on an annual average basis at SFWMD water control structures S-5A, S-6, S-7, S-150, and S-8 (**Figure 1**). For possible future use, additional simulations were run to determine STA size for annual average discharge concentrations of 40, 30, and 20 ppb.

Annual average phosphorus inputs (metric tons) were determined for input to the model (**Table 4**) with adjustments made for water supply bypass, and EAA acreage to be removed from production and used as STAs. Adjustments correspond to that portion of the total average load (205 metric tons) for the period of record that will not require treatment by the STAs. Adjustments for TP in water supply bypass were made because it represents a portion of the 205 metric tons discharged through the structures that cannot be attributable to agricultural practices. Adjustments were made for EAA acreage that would be transformed into STAs because the acreage is expected to no longer export TP as it did when it was farmed. Adjustments for EAA acreage will vary as a function of STA TP discharge concentration goals (e.g. desired low TP discharge concentrations require additional STA acreage).

Another adjustment to TP loads would result from implementation of agricultural BMPs. BMPs are to achieve a 25 percent reduction in TP load to the STAs. For possible future use, additional simulations were run to determine the effect on required STA area if the BMPs were more or less efficient than this percentage.

Table 4. Phosphorus loads (metric tons) to STAs through SFWMD structures after adjustments.*

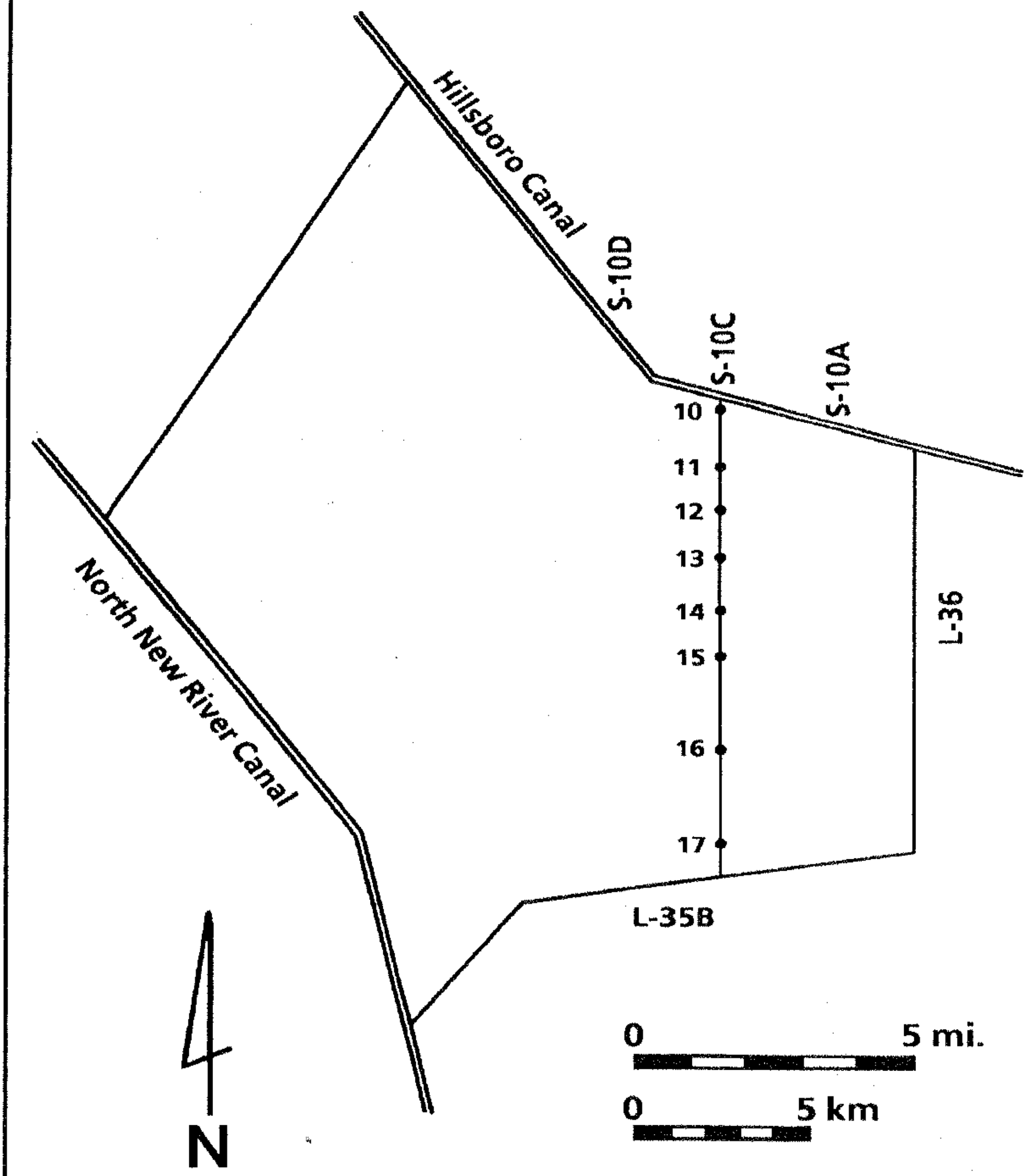
STA	A Average POR TP Load	B Water Supply Bypass	C Land Converted to STAs**	A-(B+C) Adjusted POR TP Load	0.75 × [A-(B+C)] Adjusted for EAA BMPs
1 (S-5A)	77	0.96	7.7	68	51
2 (S-6)	28	3.1	0.99	24	18
3 (S-7+S-150)	33	4.2	1.0	28	21
4 (S-8)	67	2.7	5.6	59	44
	205	10.9	15.3	179	134

* numbers may not add up exactly due to rounding
50 ppb effluent goal
8 m/y apparent settling rate
25% TP retention by BMPs
20% maximum water retention by BMPs
** estimates based upon refined estimates (@ 9/9/91) of basin sizes and phosphorus loads.

Bulk total phosphorus inputs from atmospheric sources were set at 30, 30, 30, and 50 ppb for STA 1, 2, 3, and 4, respectively. For modeling convenience, the input of bulk total phosphorus from atmospheric sources was computed by multiplying concentration by rainfall volume (**Table 2**). In reality, the dry portion of bulk phosphorus input would not be associated with rainfall volume.

Net flux of phosphorus to soils. Net flux of phosphorus per unit area of STA (mass/length^2) is calculated in the model by multiplying aqueous TP concentrations (mass/length^3) by an apparent settling rate coefficient (length/time). The settling rate coefficient was estimated from data collected in WCA-2A, and was also determined independently from modeling experiments. In the former case, aqueous and sediment TP concentrations were measured along a transect in WCA-2A (**Figure 3**). The transect starts at the S10 structures, through which high nutrient EAA runoff water has flowed into WCA-2A for about 30 years. In essence, the area of WCA-2A affected by this EAA runoff has performed as an STA. Therefore, net TP deposition rates measured in sediments of WCA-2A could be expected in STAs when built. Using ^{137}Cs dating techniques, net TP flux rates along the transect were estimated and two regression equations were developed that describe the net flux (g TP/m^2/y) as a function of distance from the S-10 sources (per. comm. M. Koch, SFWMD, 1991).

Figure 3. WCA-2A showing transect along which sediment accumulation rates were estimated.



26 y net TP deposition rate = 0.758 - 0.243 * ln (distance, mi) $r^2=0.945$ (1)

5 y net TP deposition rate = 0.95585 - 0.95323 * LOG (distance, mi) $r^2=0.850$ (2)

Similarly, a regression of aqueous TP concentrations (g/m^3) measured along the same transect was developed for the period 1986 - 1990 (no samples were taken in 1989 due to drought conditions):

TP concentration = 0.13165 - 0.16159 * LOG (distance, mi) $r^2=0.98$ (3)

By dividing the dependent variable of the deposition regression by the concentration regression, an estimate of the apparent settling rate coefficient (m/y) versus distance is obtained. Apparent settling rate coefficient values increased over the first four miles of the transect from 4.8 to 12.3 m/y (average = 7.7 m/y) using the 26 year deposition regression and from 6.7 to 11.1 m/y (average = 8.4 m/y) using the five year deposition regression.

Another approach was used to check the reasonableness of the calculated apparent settling rate coefficients. This was done by constructing a phosphorus mass balance model of WCA-2A, using the equations in **Table 1** and **Table 2**. Assuming standard precipitation and evaporation rates (discussed above), and knowing the average annual phosphorus load for the period of record from the S-10 structures (60 MT, 1989 draft Everglades SWIM plan), average surface water inflow (0.43 Km^3, 1989 draft Everglades SWIM plan), average retention time (73 d, 1989 draft Everglades SWIM plan), and impacted acreage (24000 ac, 1989 draft Everglades SWIM plan), the model was run with three apparent settling rate coefficient settings to see if measured net TP fluxes along the WCA-2A transect could be predicted. The results of these simulations (**Figure 4**) indicate that the apparent settling rate coefficient setting in WCA-2A should fall between 6 and 10 m/y, very similar to that which could be calculated from the empirical evidence above. Therefore, there is a large degree of confidence in employing a settling rate of 8 m/y to calculate STA sizes. In comparison with settling rates measured in 50 other wetland sites worldwide, the 8 m/y value is large, but not out of the range of possible values (**Figure 5**).

C. RESULTS

Using the adjusted hydrologic flows (**Table 3**) and adjusted phosphorus loads (**Table 4**), and other conditions discussed above, the STA size necessary to discharge 50 ppb into the Water Conservations Areas on an annual average basis was computed (**Table 5**). Approximately 6.5 percent additional acreage was added to the effective STA size for required containment berms. The percent reduction of unadjusted TP load to each basin was S5A, 83.8%; S6, 77.4%; S7, 66.6%; S8, 85.5%. For the entire EAA, the percent reduction of unadjusted loads was 81.0%.

The effect of BMP performance on the effective STA size required to reach 50 ppb in discharges to the Water Conservations Areas on an annual average basis was also computed (**Table 6**). Phosphorus load reductions tested ranged between zero and 40 percent effective; associated water reductions tested ranged between 0 and 32 percent. As the effectiveness of load (and associated water) reductions decreased, the amount of STA land required to discharge 50 ppb increased. Conversely, as the effectiveness of load (and associated water) reductions increased, the amount of STA land required to discharge 50 ppb decreased. Similar relationships were found for desired discharge concentrations of 40, 30, and 20 ppb (Table 7). In general, as desired discharge concentrations decreased, the amount of land required for the STAs increased.

Figure 4. Simulated and measured net phosphorus flux to sediments of WCA-2A. The effect of three apparent settling rates (values indicated on lines, m/y) on simulated net phosphorus flux to sediments is shown.

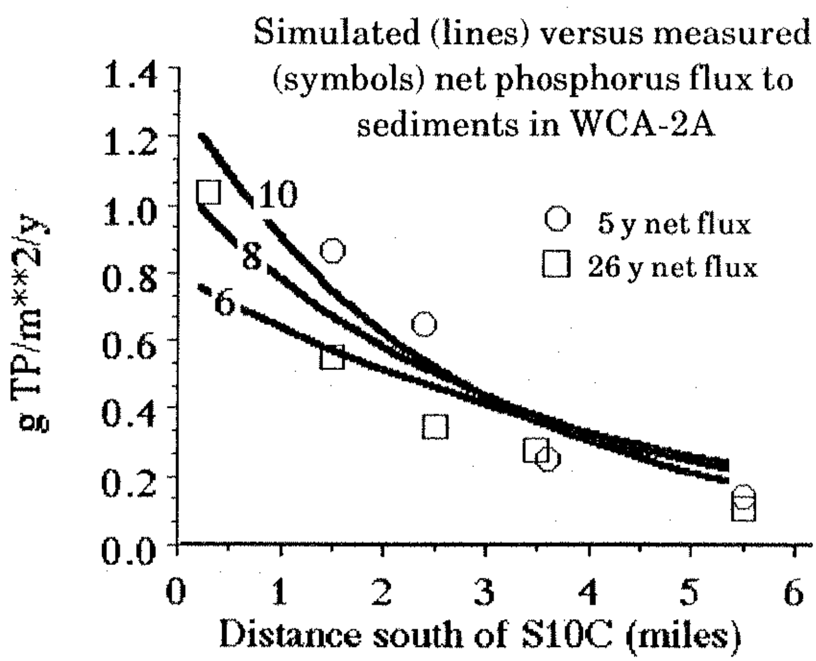
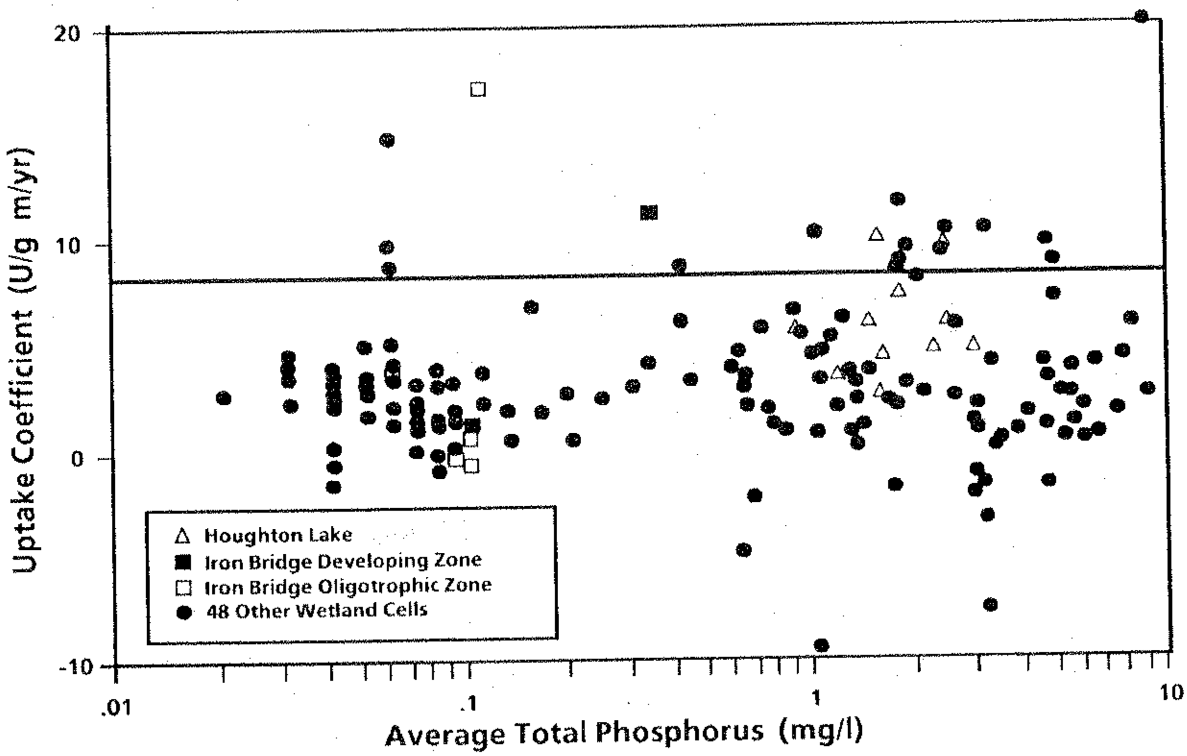


Figure 5. Apparent settling rate coefficients measured 50 wetland sites worldwide. The 8 m/y value used in calculating STA size is indicated by a horizontal line.



per. comm. Dr. Robert Kadlec, Univ. of Michigan, 1991.

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Table 5. Effective acreage required for STAs to reach 50 ppb total phosphorus discharge concentrations.*

Basin	STA	Effective Treatment Area (acres)	Total Area including Levees (acres)
S-5A	STA-1	12,185	12,977
S-6	STA-2	4,540	4,835
S-7	STA-3	4,705	5,011
S-8	STA-4	11,170	11,896
TOTALS		32,600	34,719

* Apparent settling rate = 8 m/y
BMP performance = 25% TP reduction and max. 20% water reduction
Numbers reflect revised estimates (@ 10/21/91) of basin acreages and phosphorus loads.

Table 6. Effective acreage required for STAs to reach 50 ppb TP discharge concentrations, under varying conditions of BMP performance.*

% BMP TP load reduction	0	15	25	40
% BMP water reduction	0	12	20	32
S-5A (STA-1)	15,010	13,120	11,800	9,750
S-6 (STA-2)	4,900	4,190	3,700	2,950
S-7 (STA-3)	6,650	5,635	4,950	3,850
S-8 (STA-4)	15,375	13,460	12,150	10,075
TOTALS	41,935	36,405	32,600	34,750

* Apparent settling rate = 8 m/y
Does NOT yet reflect 10/21/91 revisions to basin size and phosphorus loads.

Table 7. Effective acreage for all STAs to reach goals indicated.*

% BMP TP LOAD REDUCTION	% BMP WATER REDUCTION	SETTLING RATE m/y		
		6	8	10
Goal = 40 ppb				
0	0	65125	49645	40155
15	12	57280	43405	35212
25	20	51815	39125	31400
40	32	43160	32345	25875
Goal = 30 ppb				
0	0	77972	59655	48335
15	12	69115	52525	42673
25	20	62975	47615	38320
40	32	53120	39830	31910
Goal = 20 ppb				
0	0	96780	74150	60119
15	12	86702	65795	53509
25	20	79470	60025	48350
40	32	68050	50895	40725

*Does NOT yet reflect differences due to revised (10/21/91) basin acreages and phosphorus loads.